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Analyzing temporal patterns of knowledge construction in a role-based online discussion

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Abstract This paper introduces an approach to analyze temporal patterns of knowledge construction (KC) in online discussions, including consequences of role assignments. The paper illustrates the power of this approach for illuminating collaborative processes using data from a semester-long series of discussions in which 21 university students were assigned weekly roles. The KC contributions of all 252 posts in the discussion were coded using a five phase scheme (Gunawardena et al. 1997). Then, statistical discourse analysis was applied to identify segments of discussion characterized by particular aspects of KC, and "pivotal posts"—those posts which initiated new segments of discussion. Finally, the influences of assigned student roles on pivotal posts and KC were modeled. The results indicate that most online discussions had a single pivotal post separating the discussion into two distinct segments: the first dominated by a lower KC phase; the second dominated by a higher KC phase. This provides empirical evidence supporting the progressive nature of the KC process, but not the necessity of the full five-phase sequence. The pivotal posts that initiated later segments were often contributed mid-discussion by students playing one of two summarizing roles (Synthesizer and Wrapper). This suggests that assigning a summarizing role mid-discussion can aid group progress to more advanced phases of KC. Finally, in some discussion segments, the KC phase of a post was related to characteristics of the two preceding posts. Collectively, the results demonstrate the power of this temporal approach for investigating interdependencies in collaborative KC in online discussions.

Keywords Quantitative analysis of CSCL · Temporal analysis · Multilevel modeling · Content analysis · Computer mediated communication · Asynchronous discussion groups · Scripting · Role taking

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Introduction

The field of CSCL is interested in patterns of knowledge construction (KC) in online discussion forums, a tool used extensively in both online and blended college courses. Examining KC patterns can increase our understanding of the processes by which students co-construct understanding, and can inform both the instruction and design of online discussion forums. Of particular concern both practically and theoretically are the aspects of KC that take place; one popular categorization of these aspects is that of Gunawardena et al. (1997) which conceptualizes the KC process in five phases: (1) Sharing Information, (2) Exploring Dissonance, (3) Negotiating Meaning, (4) Testing and Modifying, and (5) Summarizing and Applying. Unfortunately, most analyses of KC in online discussions aggregate counts of posts in the different phases, losing important information about sequencing, and hence patterns of KC. For example, one hypothesis in CSCL research is that assigning roles to students can increase positive interdependence among students (e.g. Strijbos et al. 2004, see also Johnson and Johnson 1992) and thereby help them achieve more advanced phases of KC. But aggregate totals of KC phases of posts cannot test specific hypotheses about how group members' posts affect one another or the process by which the group reaches advanced phases of KC.

This paper introduces an approach to analyze temporal patterns of KC in online discussions, including consequences of role assignments. In particular, it uses a combination of content analysis and statistical discourse analysis to distinguish segments of KC patterns, identify posts that initiate new segments of discussion (referred to as *pivotal posts*) and model relationships between sequential posts. The paper illustrates this approach with data from a case study of a semester-long series of role-based discussions by 21 students. Using Gunawardena et al.'s (1997) scheme of five phases of KC and definition of several student roles, we test hypotheses about patterns of phases of KC and model the effects of role assignments on these patterns.

The process of knowledge construction (KC)

Researchers have proposed multiple models to conceptualize and assess the process of KC during asynchronous discussions (e.g. Pena-Shaff and Nicholls 2004; Veerman and Veldhuis-Diermanse 2001; Weinberger and Fischer 2006). We employ Gunawardena's Interaction Analysis Model for Examining Social Construction of Knowledge (Gunawardena et al. 1997) for several reasons. First, the model explicitly conceptualizes the sequential relationship between different KC phases, thus providing testable hypotheses of predicted KC patterns. Second, it is both theoretically and empirically grounded (De Wever et al. 2006) and attempts to capture "the complete process of negotiation" (Gunawardena et al. 1997, p. 413) involved in KC. Thirdly, the KC phases are relatively straightforward to evaluate (Lally 2001). Finally, it has been used extensively as a measure of KC in studies involving roles (e.g., De Wever et al. 2007; Yang et al. 2005), thus allowing for comparison with relevant past findings. Our analysis approach can also be used to examine patterns in online discussions using other KC models.

In Gunawardena et al.'s (1997) model, KC occurs in a series of successive (though not necessarily strictly sequential) phases that can be viewed as moving generally from lower to higher mental functions. In the model, learners begin by sharing, clarifying, and elaborating ideas (Phase 1: *Sharing Information*). Then, conflicts among them are explored (Phase 2: *Exploring Dissonance*). Next, learners reconcile conflicting ideas by negotiating their meanings and co-constructing new knowledge propositions (Phase 3: *Negotiating Meaning*). Learners may then test and revise their synthesized ideas (Phase 4: *Testing and Modifying*). Finally, they can state and apply their new knowledge (Phase 5: *Agreeing and Applying*). See Table 1 for detailed descriptions and examples of each of the phases. The drive is to achieve higher phases of KC; however, successive phases build on each other. Hence, *all* phases contribute to the KC process (Gunawardena et al. 1997).

While Gunawardena et al.'s (1997) model conceptualizes knowledge construction as a process which occurs though learners' interactions (via their posts), previous work has not capitalized on its capacity to examine this process by analyzing *patterns* of KC. Past studies have often evaluated discussion quality by counting the posts in each KC phase (e.g., Marra et al. 2004; Schellens et al. 2007) or by computing the discussion's average KC phase (e.g., Schellens et al. 2005). These compiled measures treat KC as an outcome variable where more posts in higher KC phases indicate better learning, even though the scheme is a model of the *process* of constructing knowledge. Importantly, two discussions can proceed quite differently, while having the same KC phase counts (e.g., a sequence of posts with KC phases 1212312123 vs. 1111222233). By treating KC as an aggregate outcome of individual contributions, prior studies failed to test a central underlying premise of the model: groups construct knowledge through a specific sequence of phases. In this study, we addressed this issue by analyzing how the *group* proceeds through the phases of the KC *process*.

t1.1 **Table 1** Summary of the five phases of Knowledge Construction (KC) based on Gunawardena et al. (1997)

	Phase	Title	Description	Example
t1.2	Phase	Title	Description	Example
t1.3	1	Sharing information	Statements of observation, opinion, agreement, clarification, example or problem definition etc.	"I agree that students' pre-existing ideas are important to consider. There is empirical support for this in the misconceptions literature."
t1.4	2	Exploring dissonance	Identification of areas of disagreement; clarification of source and extent of disagreement; providing support for one's ideas in the face of counterarguments.	"I think what we are disagreeing about here is not whether we should assess learning but how to design assessments to drive positive learning experiences."
t1.5	3	Negotiating meaning / co-constructing knowledge	Identification areas of agreement across conflicting ideas; clarification of meanings of terms; proposal and negotiation of integrating metaphors and compromise statements.	"I think that if we take an 'expert' as someone who sees the deep structure of a discipline, then we can all agree that more than rote memorization is needed."
t1.6	4	Testing / modifying proposed synthesis	Testing the proposed synthesis against "received facts," cognitive schema, personal experience, collected data, and expert testimonies.	"We agreed that peer-interaction is important for learning, but what about all the research on self-study and individual tutoring systems?"
t1.7	5	Agreeing / applying new knowledge	Summarization of agreement(s); application of new knowledge; metacognitive statements of changes in knowledge or ways of thinking.	"I think our discussion has shown that it is not just the learning materials that matter, but how they are used. I guess the next question is how to help students use materials well…"

Possible KC patterns

Gunawardena et al.'s (1997) model suggests two possible KC patterns described below, but others are also theoretically possible. By identifying these patterns' characteristics, we can empirically test for them. Note that these patterns are descriptive; future work will evaluate their benefits, drawbacks and relationship to KC outcomes.

Theoretically predicted pattern 1a: Strictly progressive segments for each KC phase

One interpretation of Gunawardena et al. (1997) views the KC phases as a strictly increasing sequence. Viewing KC as an interdependent process and a cumulative group effort, an individual's progress through the phases depends on and influences other group members, stimulating them to proceed through the phases more-or-less together. Transitions between the phases can thus be viewed as initiated by a "pivotal post:" a contribution by a student (or the instructor) which changes the mode of discussion from one phase to another. Our notion of pivotal posts and their role in online discussions resonates with other recent work in the CSCL community to define and identify pivotal moments in collaboration (Lund et al. 2009; Stahl and Rosé 2011; Wee and Looi 2007).

A discussion that follows a strictly progressive sequence of the KC phases might proceed as follows. Initially, learners share ideas (a series of KC Phase 1 posts, e.g., 11). For example, see Cathy and Sandeep's start of a sample online discussion below in which students are discussing if rote memorization is a useful learning strategy.

> Cathy (KC Phase 1): I think that students who use rote memorization are taking a big risk. They learn a lot of specific facts, but won't be able to do anything with them…
> Sandeep (KC Phase 1): Good point Cathy, I think the Geography class example we talked about really supports your point. Students could define igneous fusion but…

When a learner disagrees with another group member's idea (KC Phase 2), others may not always engage. Instead, they might continue proposing new ideas (e.g., 11211, see Allan, Patricia and Dawn's additional posts below). In this case, the discussion continues in a sharing mode, identified by the dominance of posts in KC Phase 1 (with occasional posts in other phases).

> Allan (KC Phase 2): I have to disagree with you Cathy, I think students need to memorize some things before they can take on harder tasks…
> Patricia (KC Phase 1): I think an important idea we haven't mentioned is transfer. Learning isn't worthwhile unless students can use it in the future situations…
> Dawn (KC Phase 1): I think a memorization is a strategy that we use all the time. It is not the only strategy but it's important to build a vocabulary to talk …

In contrast, a disagreement can act as a *pivotal post* that radically changes the mode of discussion. In this case because the pivotal post is a disagreement, the new mode of discussion becomes that of exploring disagreements (e.g., 11211→**2**22, the pivotal post is indicated in **bold**). For example, Steve's disagreeing post sparks a series of disagreeing posts by Mei and Ana (also see Chiu and Khoo 2003).

> Steve (KC Phase 2): I think the main point of contention in the different ideas people are throwing out isn't *if* memorization is one way to learn basic concepts, but *how much* memorization is useful…

> Mei (KC Phase 2): Actually, I think the differences in ideas we have might be less about "how much" memorization and more about "when" it is a useful strategy…
> Ana (KC Phase 2): I remember reading that experts organize information in a meaningful way. If advanced students can't really memorize rotely then I don't know if we can accept Dawn's claim that we use the strategy "all the time"…

At some point, a learner may attempt to reconcile views presented in different posts (KC Phase 3). This can provide a more cohesive view of disparate ideas—a common base around which group members can negotiate shared understandings (e.g. Kauffeld and Meyers 2009). If others follow suit, the post serves as another pivotal post, and the group transitions from debating to reconciling ideas (e.g., 222→**3**3233). Next, a learner may start to test the negotiated idea(s) (KC Phase 4) which can stimulate more testing and revision of the idea(s), thereby creating another discussion segment in a more advanced KC phase (e.g., 33233→**4**454344). Finally, if a learner formalizes and applies the revised idea(s), this can spark other applications in a KC Phase 5 discussion segment (e.g., 4454344→**5**5545). This hypothetical discussion follows Gunawardena et al.'s model of a "complete" knowledge construction process; it consists of five distinct, progressively increasing KC segments with changes initiated by four pivotal posts (11211→**2**22→**3**3233→**4**454344→**5**5545).

Theoretically predicted pattern 1b: Progressive and regressive segments for each KC phase

Knowledge construction is not always a strictly linear process (Paavola et al. 2004). Thus another interpretation of Gunawardena et al. (1997) recognizes earlier phases as logically prior to later phases, but also allows regressive segments: segments dominated by lower KC phases than the previous segment. For example, a tentatively shared synthesis (KC Phase 3) might break down when a learner returns to debating the merits of a particular idea (KC Phase 2) and others follow suit (e.g., 11211→**2**22→**3**3233→**2**212). In this pattern any number of segments can occur and the return to a "lower" phase as part of the KC process is not necessarily negative for the discussion.

Alternative pattern 2a: Strictly progressive segments, but some KC phases skipped and 2b: Progressive and regressive segments, but some KC phases skipped

There are other theoretical alternatives to the ones Gunawardena et al. (1997) suggest. One possibility is that groups might skip one or more KC phases. For example, learners might share their ideas (e.g., 111211) and then propose a compromise among them (111211→**3**333) without exploring their differences or disagreements (skipping KC Phase 2). Then, they might conclude their discussion without testing (Phase 4) or applying it (Phase 5). In this case, the discussion has only two segments (111211→**3**333), each segment is dominated primarily by posts in one KC phase, and KC increases in each subsequent segment. This pattern of segments with skipped KC phases can be strictly progressive (pattern 2a) or include regressive segments (pattern 2b; e.g. 111211→**3**333→**2**2122). In both cases the patterns do not require passing through all earlier phases to reach later ones.

Alternative pattern 3: Mixed KC phase segments

It is also theoretically possible that during some discussion segments, a group may engage in several KC phases such that none dominates. For example, after group members share ideas (111), one learner disagrees with an idea or explores the dissonance between them (KC Phase 2). While some group members follow suit, others continue to brainstorm new ideas (KC Phase 1) and still others begin to negotiate a resolution of the different ideas (KC Phase 3). Collectively, the KC phases of posts after the disagreement are distinct from those before it, and thus a pivotal post and new discussion segment can be said to occur (e.g., 11211→32432); however, the latter segment is not defined by a particular KC phase. Hence this pattern indicates a segmented discussion with some segments that do not have a shared mode of interaction.

Alternative pattern 4: No distinct segments of KC

Finally, it is possible that a discussion might have no distinct segments of higher KC or lower KC. Such an irregular pattern could have increases or decreases in KC at any time, thus no coherent segments or pivotal posts are identifiable (e.g., a post sequence of KC 153142151431). This pattern indicates a discussion without any shared mode of interaction, i.e., sequences of posts do not affect one another.

Table 2 summarizes the empirical findings that would support or reject each KC pattern. In the next section we discuss how assigned student roles and the functions they ask learners to perform align with the KC phases and might influence the above KC patterns.

Supporting KC in online discussions with assigned student roles

Online learning conversations often do not realize their potential as sites of rich KC. Typically they remain exercises in listing ideas rather than rich interactions that construct shared understandings (Guzdial and Turns 2000; Herring 1999; Thomas 2002). One way to increase the likelihood of valuable learning interactions is by assigning roles to students to script their collaboration (Dillenbourg 1999). Roles give students guidance about how to interact with one another productively (O'Donnell and Dansereau 1992), i.e., in ways that promote desired cognitive, metacognitive and socio-cognitive processes (King 2007).

For example, early work in face-to-face contexts showed positive effects on reading comprehension when student pairs took turns playing the roles of recaller and listener (*scripted cooperation*; Dansereau 1988) questioner, summarizer, clarifier and predictor (*reciprocal teaching*; Palinscar and Brown 1984) or questioners and explainers (*ask to think—tel why*; King 1997). In an online context, roles are often scripted to guide learners in small-groups (rather than dyads) and address the coordination challenges inherent in the medium (Haake and Pfister 2007). Common roles assigned in online discussions include moderator, starter, wrapper, responder and summarizer (e.g., Schellens et al. 2005; Strijbos et al. 2004).

Roles can support collaborative KC in online discussions by creating positive interdependence and mutual accountability among students (Schellens et al. 2007; Strijbos et al. 2004) leading to increased interaction (Hara et al. 2000; Seo 2007) and integration of discourse (Persell 2004; Tagg 1994). Roles can also support students' metacognitive awareness of their contributions to the group's KC (Persell 2004; Strijbos et al. 2004) helping them to self-moderate discussions and increase their autonomy, ownership, motivation and responsibility for learning (Seo 2007; Tagg 1994). However, not all roles influence posts' KC, and specific assigned roles can have different influences (for example t2.1 **Table 2** Relationship of potential findings to KC patterns

	Finding	Patterns of Segments Sequences					
t2.3		1a: Strictly progressive segments for each KC phase	1b: Progressive and regressive segments for each KC phase	2a: Strictly progressive segments, but some KC phases skipped	2b: Progressive and regressive segments, but some KC phases skipped	3: Mixed KC phase segments	4: No distinct segments of KC
t2.4	Distinctsegments of discussion	√	√	√	√	√	
t2.5	Segments dominated by one KC phase	√	√	√	√		
t2.6	KC onlyincreases acrosssegments	√		√			
t2.7	Advanced phase segment occurs only after all lower phase segments[a]	√	√				
t2.8	Example	11211→**2**22→**3**3233→**4**45344→**5**5545	11211→**2**22→**3**3233→**2**212→**4**45344→**5**5545	11211→**3**333→**5**5545	11211→**3**333→**2**2122→**5**5545	11211→**3**2432→**5**55	153142151431

[a] If a segment is dominated by an advanced phase of KC, it only occurs after segments dominated by each of the lower phases. For example, a segment dominated by KC phase 3 only occurs after at least two earlier segments, one dominated by KC phase 1 and one dominated by KC phase 2

contrast the positive effects of the “Wrapper” role with the negative effects of the “Source Searcher” role in De Wever et al. 2007 and Schellens et al. 2005, 2007).

While past research suggests that particular roles can have a positive impact on KC during online discussions (Schellens et al. 2007), research gaps remain. In particular, researchers have not examined the interdependent nature of the group processes underlying KC, in which each learner’s posts help build the context for others’ future posts. Specifically, work is needed to investigate how role-based posts influence other participant’s postings and overall group KC patterns. To consider how specific roles may interact with the KC process, we can examine the alignment between the KC phases and the specific functions that each role asks a learner to enact. If a role asks a learner to perform a function that aligns with a KC phase different from the KC phase of the group members’ current posts, that contribution could act as a pivotal post that initiates discussion in a new KC phase.

Building on De Wever et al.’s (2007) efforts to assess role enactment, Wise et al. (2010a) analyzed assigned roles in the literature and identified six core conversational functions that they ask learners to perform: Introduce New Idea, Bring in Source, Use Theory, Respond, Give Direction, and Summarize. We propose that some of these functions conceptually align with specific KC phases, while others are phase-independent and support the overall KC process (see Table 3). Specifically, we focus our attention on the Summarize function and its associated roles because it theoretically aligns with advanced phases of knowledge construction (De Wever et al. 2007; Schellens et al. 2005, 2007).

Learners in summarizing roles may create pivotal posts that advance KC

Summarize is a synthetic function that asks a learner to organize and integrate different ideas in the discussion (Wise et al. 2010a; Xin et al., 2011). For example, in a discussion on lesson planning for mathematics, a learner can describe how several very different suggested activities for teaching parallel lines could be combined. Cognitively, this helps the summarizing learner (and potentially those who read the post) to

Table 3 Alignment of previously assigned roles, the functions they ask learners to serve, and the knowledge construction (KC) process

Role	Function					
	New Idea	Bring in Source	Use Theory	Respond	Give Direction	Summarize
Starter	X				X	
Source-Searcher		X				
Theoretician			X			
Questioner				X		
Devil’s Advocate				X		
Moderator	X			X	X	X
Wrapper						X
Theoretical alignment with KC Phases	1	1	1			3 or 5
Relationship with KC in past studies[a]	−	−	0	?	?	+

[a] (Schellens et al. 2005, 2007; De Wever et al. 2007). Symbols indicate a positive effect (+), a negative effect (−), no effect (0), or not yet studied (?)

consolidate their understanding of different ideas. Socio-cognitively, summarizing posts can support the group in building on the existing discussion, maintaining joint attention and coordinating activity. In this way summarizing roles can help address the common problem of fractured and incoherent online discussions (Herring 1999; Thomas 2002).

A summarizing post can identify areas of agreement and aid compromises between contested ideas (which align theoretically with KC Phase 3, Negotiation of Shared Meaning). Or, it can help group members reach a final agreement and recognize changes in their ideas (which aligns with KC Phase 5, Statement/ Application). However, while empirical studies show that summarizing *posts* consistently contribute at a high KC phase (De Wever et al. 2007; Schellens et al. 2005, 2007), *groups* assigned roles with a summarizing function have not consistently outperformed those without one (e.g., compare Schellens et al. 2005 and 2007). One reason other group members may not realize the benefits of summarizing posts is that the Summarize function is often assigned to a Wrapper role asked to conclude a discussion (Schellens et al. 2005, 2007; see also Hara et al. 2000; Zhu 1998). Since a Wrapper generally summarizes at the end of a discussion, other group members are unlikely to make subsequent posts and thus realize the coordination benefits described above.

We propose using the Summarize function in the middle of a discussion to synthesize discussion strands, maintain joint attention and ground subsequent discussion. While few students are likely to post after the Wrapper at the end of a discussion, many more are likely to build on a midway summary that helps them integrate their understanding of the various ideas. Reading a summarizing post can prompt them to join the synthetic effort—moving beyond sharing, comparing and debating their ideas to co-construct shared understandings in their group. As more students do this, they create more posts in higher KC phases for one another to read, compounding these processes until the whole group collectively climbs to a higher phase of KC. In this way, a midway summarizing post is potentially a pivotal post that can elevate a group to a higher KC phase, helping to solve the insidious problem of online discussions stuck in the rut of simply listing ideas without developing them collaboratively (Thomas 2002).

Other roles that might affect KC processes

Of the five other identified conversational functions, three align with a specific KC phase and thus, roles that elicit them might affect group KC patterns. These three functions (New Idea, Bring in Source and Use Theory) all ask learners to input specific kinds of information into a discussion (Wise et al. 2010a) and thus theoretically align with KC Phase 1 (Sharing). If a group is already at an advanced phase of KC (e.g. negotiating a shared understanding in Phase 3) then posts made in KC Phase 1 could act as regressive pivotal posts that push the discussion away from synthesis and back towards an earlier phase of KC. This may or may not be beneficial for the discussion depending on its current state.

Empirically, both the New Idea and Bring in Source functions (though not Use Theory) have been associated with posts in low KC phases (De Wever et al. 2007; Schellens et al. 2005, 2007); however, effects on subsequent posts have not yet been studied. The remaining two functions, Respond and Give Direction, appear to support KC generally, rather than being aligned with a specific KC phase and thus are not expected to affect group KC patterns. Roles that commonly assign each of these functions are shown in Table 3. While we have proposed connections among specific roles, functions, and pivotal posts above, pivotal posts can also arise from a group member simply posting in a new phase.

Overview of the current study

Past work has looked at KC in aggregate, losing important information about patterns of KC and how they may be influenced by the assignment of student roles. In addition, the beneficial Summarize function has been primarily assigned to roles at the end of discussions, limiting its potential to elevate group KC processes. In this study, we used a temporal analysis to examine KC as a process in a series of role-based discussions. One particular role ("Synthesizer") was used to elicit a Summary midway through each discussion. We asked the following questions:

1. What pattern(s) characterize KC processes during an online, asynchronous discussion with assigned roles?
2. Does a summary midway through the discussion affect subsequent KC?
3. How do the assigned roles and functions of recent posts affect the current KC process?

Based on the above examination of roles and KC patterns, we predicted that some posts would act as pivotal posts, dividing discussions into distinct identifiable segments. The Synthesizer role (Summarize function) was expected to create pivotal posts that had a progressive influence on the group's KC process, elevating the discussion to KC Phase 3 or 5. The nature of other pivotal posts, whether the discussion segments are clearly dominated by a single KC phase, whether all five phases are represented, whether KC only increases between segments, and whether characteristics of recent posts are antecedents of specific KC phases remained empirical questions.

Time-based methods for analyzing KC

As discussed above, group interactions in collaborative learning scenarios are inherently interconnected and dynamically affect one another over multiple time scales (Lemke 2000). Recent posts (e.g., asking a question) create a local time context (*micro-time context*) that can influence the next post(s). Also, students may have different modes of interaction across the course of a discussion that can result in distinct segments of discussion dominated by different KC phases (*meso-time contexts*). Several researchers (Chiu and Khoo 2005; Mercer 2008; Reimann 2009) have criticized past research on collaborative learning for ignoring these micro- and meso- contexts of time. In this study we used both micro- and meso- time contexts to investigate the interdependencies and relationships between learner contributions to the dynamic process of knowledge construction in online discussions.

We first used content analysis to code the posts for variables of interest (e.g. KC phase and enactment of functions assigned to roles). We then used statistical discourse analysis (SDA) (Chiu and Khoo 2005) to model relationships across the different levels. To investigate meso-time contexts, we used SDA to statistically identify pivotal posts and discussion segments based on the KC exhibited in posts. This analysis objectively detected discussion segments without relying on subjective human assessments, and importantly identified pivotal posts whether provoked by the intervention or other causes. To investigate micro-time contexts we used the post as the unit of analysis, and applied SDA to examine how characteristics of recent posts might influence the KC phase of the current post. As we had explanatory variables at different levels of time and interdependency of data between group members (Cress 2008), we used a multilevel analysis (also known as hierarchical linear modeling, Bryk and Raudenbush 1992; Goldstein 1995) to model relationships among explanatory variables and KC. Multilevel analysis separates the outcome variable's variation into differences at various levels of nesting (post characteristic, time period, weekly topic, group history, and so on) and estimates how much of these differences at each level is explained by each explanatory variable.

Methods

Participants

Participants were 21 students (8 women, 13 men) in a Foundations of Educational Technology course at a university in western Canada. Seven of the 21 participants were of Asian descent. The blended course (face-to-face and online) was an elective for the ten undergraduate students in the teaching preparation program, required for the seven graduate students in the Educational Technology masters program and open to the three practicing teachers and an additional graduate student. Class members formed two discussion groups: (a) undergraduates and (b) graduate students and teachers.

Learning context

The course had thirteen weekly face-to-face meetings and nine weeks of online asynchronous discussion. Faced with a weekly, authentic, instructional design challenge, each group had to collectively create a suitable educational design (e.g., activity plan). For example, during one week they had to design a set of activities to help a group of 10 year-olds become "experts" in the Chinese Zodiac. Students had to make at least two postings each week for the first six weeks and at least one posting per week for the final three weeks. Participation in these discussions counted for 15% of a student's course grade.

Discussion tool

Open-source LMS Moodle (http://moodle.org/) served as the asynchronous, threaded, online discussion environment. Students could read and reply to one another's posts with unlimited thread depth. Although Moodle allows thread splitting, automatic quotation of others' posts and marginal annotations, none of the participants used these features. The 21 students wrote a total of 252 posts (evenly divided across the groups) during the online asynchronous discussion.

Procedure and role assignment

During a face-to-face session at the beginning of the course, the instructor introduced the students to the online discussion tool, the discussion format, and their roles via a role description guide. The instructor modeled the roles for the first discussion week. During the following eight weeks, students were assigned roles and participated in the online discussion. The 10 roles (see Table 4) were randomly assigned and rotated so that each student played a different role in each of the eight role-based weeks. Students assigned a t4.1 **Table 4** Functionally-based roles assigned with abbreviated student instructions

	Role	Function(s)	Description
t4.2	Role	Function(s)	Description
t4.3	Starter	New Idea Give Direction	Start off the discussion by responding to the instructor's questions based on the assigned readings and raising what you see as the most important issues.
t4.4	Inventor	New Idea	Generate fresh and creative ideas and new perspectives on the questions being discussed that have not been brought up yet in the discussion.
t4.5	Importer	New Idea Bring in Source	Bring outside ideas into the discussion. The ideas may come from materials of other classes or the news and should bring in a new perspective.
t4.6	Mini-me	Use Theory	Represent the author of one of the assigned reading's position on the questions being discussed.
t4.7	Elaborator	Respond	Expand or provide some support for an idea someone else has already put out in the discussion.
t4.8	Questioner	Respond	Push others to go deeper and elaborate on their ideas through asking questions. You may want to ask questions such as "Why do you think X?" or "What implications does your point have for Y?"
t4.9	Devil's Advocate	Respond	Take a contrary position to one (or more) of your classmates' ideas and make a reasonable defense as to why this is a logical position to take.
t4.10	Traffic Director	Give Direction	Keep the discussion moving in a productive direction and get it back on track if the group strays from the main track or the discussion seems to stall.
t4.11	Synthesizer	Summarize Give Direction	Make connections between posts, pull comments together, and push the conversation forward (maybe in new directions).
t4.12	Wrapper	Summarize	Conclude the discussion. You should summarize key ideas, and point out overlapping thoughts, problems and unresolved questions.

Starter or Wrapper role could contribute other posts outside of the role. Discussion transcripts were collected for content analysis of function enactment and KC.

Content analysis

We evaluated function enactment and KC at the level of the individual post for three reasons. First, a post has clear boundaries and can be reliably identified (Rourke et al. 2001; Schellens et al. 2007). Second, from a social constructivist perspective, people learn from one another's contributions; thus, the relevant unit of analysis is the one through which they contribute–the post (Gunawardena et al. 1997). Third, students were expected to play their roles with the latitude of an entire post. Thus, breaking the post into smaller pieces could obscure the holistic use of the assigned role.

For each of the content analysis schemes, two coders trained and practiced on discussions outside this study. After training, both coders independently coded all posts in the data set. To test inter-rater reliability, we used Krippendorff's alpha (2004), which applies to any measurement level, any sample size, and any number of coders, categories or scale values–even if the data are incomplete (unlike many other inter-rater reliability measures). Its values range from −1 (maximum disagreement) to 1 (perfect agreement), and a value 0.67 or higher shows satisfactory agreement in exploratory studies (Krippendorff 2004). All disagreements between raters were discussed and resolved through consensus.

Enactment of functions

Wise et al. (2010b) developed the ASIMeC–Functional (ASIMeC–F) coding scheme to evaluate the degree to which students enact conversational *functions*. This scheme builds on De Wever et al.'s (2007) Analysis Scheme Identifying Message Characteristics (ASIMeC) which evaluated fidelity of *role* enactment. As a result, ASIMeC-F can be used to evaluate a wider variety of roles based on their functions (Wise et al. 2010b).

ASIMeC-F has six dimensions corresponding to the six conversational functions shown in Tables 3 and 4 (New Idea, Bring in Source, Use Theory, Respond, Give Direction, Summarize). Coders assessed New Idea as absent or present and the other five dimensions on a three-point ordinal scale (absent, partially present, fully present). Krippendorff's alphas were: New Idea (.65), Bring in Source (.92), Use Theory (.73), Respond (.98), Give Direction (.76), and Summarize (.88). Results involving New Ideas should be interpreted cautiously and are subject to validation in future studies.

Knowledge Construction (KC)

Coders used Gunawardena et al.'s (1997) scheme to identify the highest KC phase achieved in each post. Krippendorff's alpha for KC was .84.

Statistical analysis

The KC in each group's weekly online discussions was modeled at the micro- and meso-levels using Statistical Discourse Analysis (SDA) (Chiu 2008a; Chiu and Khoo 2005). SDA first statistically determined pivotal posts (referred to as breakpoints in statistical terminology) and discussion segments based on the KC phase exhibited in posts, then tested explanatory models for these pivotal posts, and finally tested explanatory models for the KC phase of an individual post. Several levels of variables were used in the explanatory models to capture the characteristics of student demographics, learning activities, roles and posts. The statistical power of any regression (including SDA) for this sample size of 252 posts is .99 for an effect size of .30 (α=.05; Cohen et al. 2003).

Identifying pivotal posts and online discussion segments

As discussed earlier, the KC phase of some parts of a discussion might be higher than that of others. Statistically identifying pivotal posts that divide the sequential data into segments with higher vs. lower KC allows testing of both hypotheses regarding KC patterns and whether the effects of explanatory variables differ across discussion segments.

Threaded discussions can be understood through two kinds of sequences: strict chronological and semantic chronological (see Fig. 1). A *strict chronological* sequence places each post on a time line, strictly according to its time of creation and irrespective of its references and relationships to other posts. In contrast, a *semantic chronological* sequence tracks the discussion of shared ideas by using the thread structure as the primary organizer and by using time to order same level posts. For example in Fig. 1b, posts 2 and 3 are at the same level of reply within the same thread; thus, the time that each post was created determines their order. While a semantic chronological sequence does not always

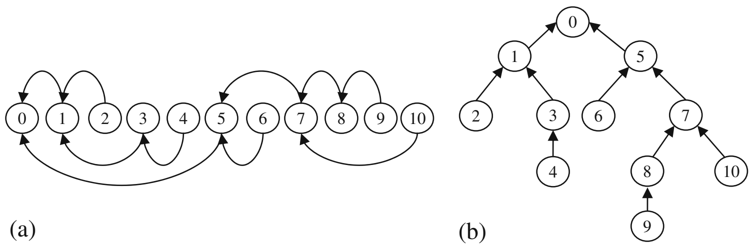

Fig. 1 Diagrams for an asynchronous threaded discussion showing (**a**) strict chronological sequence of posts and (**b**) semantic chronological sequence of posts

align with the real-time succession in which posts were created, it more accurately represents each group's development of ideas over time and thus was used to analyze the data in this study.

For each week of each group, we statistically identified pivotal posts that divided discussions into segments by using regression analysis to model different possible numbers and locations of pivotal posts and finding the model that best fit the data (Chiu and Khoo 2005). First, we modeled the KC phase of each post in a discussion under the assumption of no pivotal posts. Next, we assumed one pivotal post and tested all possible locations of the pivotal post. Then, we assumed two pivotal posts and tested all possible pairs of locations of two pivotal posts, and so on up to all possible location combinations for six pivotal posts. The best model of pivotal posts had the smallest Bayesian information criterion (BIC, also known as Schwarz information criteria, Kennedy 2004).

Modeling pivotal posts

Next, we created an explanatory model to identify characteristics associated with pivotal posts and the posts preceding them. Because we were using nested data (posts within online discussions within groups) to model a binary outcome (pivotal post vs. not) an ordinary least squares regression would be statistically inefficient and yield biased results (Goldstein 1995). Thus we applied a multilevel, binary logit regression.

We entered variables at multiple levels (e.g., activities, student characteristics, and post characteristics) in sets according to time constraints, expected causal relationships, and likely association with pivotal posts (see Table 5 for a full list of explanatory variables and their order of entry). If the variable Summarize was significant, we tested whether the effects differed across the level of summary by replacing the Summarize variable with Minor Summary and Extensive Summary. We then used lag variables to model the characteristics of the preceding posts. We first entered a set of post characteristics for the previous post (lag 1), then added the same explanatory variables for the post before that (lag 2). No variables were significant at lags greater than 2. To test for moderation effects by discussion segment, we added terms for the interaction of the above variables with a variable that indicated posts created after the first pivotal post. We used a random effects model (Goldstein 1995) to check if relationships between explanatory variables and KC differed across discussions.

To test whether each set of explanatory variables was significant, we used a nested hypothesis test (χ^2 log likelihood test, Kennedy 2004) with an alpha level of .05. We controlled for false positives (Type I errors) by using a two-stage linear step-up procedure (Benjamini et al. 2006). If a set of explanatory variables was significant, non-significant t5.1 **Table 5** Explanatory variables and their order of entry into models of pivotal posts and KC (all sets of explanatory variables were used in both models except as noted)

Discussion	t5.2
Two posts per week (Baseline = 1 post per week)	t5.3
Graduate student / Teacher group (Baseline = Undergraduate group)	t5.4
Week_1, … Week_7 (Baseline = week 8)	t5.5
After 1st pivotal post (used only to model KC)	t5.6
Student	t5.7
Graduate student (Baseline = Undergraduate)	t5.8
Teacher (Baseline = Undergraduate)	t5.9
Student_1 … Student_20 (Baseline = student 21)	t5.10
Role	t5.11
Starter	t5.12
Inventor	t5.13
Importer	t5.14
Mini-me	t5.15
Elaborator	t5.16
Questioner	t5.17
Devil’s Advocate	t5.18
Traffic Director	t5.19
Synthesizer	t5.20
Wrapper (Baseline = No role)	t5.21
Current Post Characteristics	t5.22
Post Number in Thread	t5.23
New Idea	t5.24
Bring in Source	t5.25
Use Theory	t5.26
Respond	t5.27
Give Direction	t5.28
Summarize	t5.29
Knowledge Construction (KC) (used only to model pivotal posts)	t5.30
Previous Post (lag 1) Characteristics	t5.31
Same as Current Post characteristics but for the previous post (KC included in both models)	t5.32
Two Posts ago (lag 2) Characteristics	t5.33
Same as Previous Post characteristics	t5.34
Interactions of After 1st pivotal moment X Above characteristics	t5.35

variables (if any) within that set were removed. We used multi-level mediation tests to test if a variable M mediated an X→Y relationship: X→M→Y (Krull and MacKinnon 2001). For significant mediators, we report the proportional change by computing 1−(b'/b), where b’ and b were the regression coefficients of the explanatory variable, with and without the mediating variable in the model, respectively.

Modeling KC

As above, we entered factors at multiple levels (e.g., activities, student characteristics, and post characteristics) to model the KC phase of a post (see Table 5). The procedure was the same as that of modeling pivotal posts with the following exceptions. First, KC has 5 ordered values (1, 2, 3, 4, 5), so multilevel, ordered logit was used rather than multilevel, binary logit. Second, to examine differences in KC across discussion segments we added a variable that indicated posts created after the first pivotal post. Third, in the current post characteristics variable set we did not include KC since it is the outcome variable.

Details of the content analysis schemes, equations used in the statistical analyses, and ancillary results are available at http://xxx.

Results

Descriptive statistics

Results confirmed that discussions were enacted without overrepresentations of posts from specific roles, from specific students or in particular weeks (see Table 6). The ten assigned roles yielded equal numbers of posts, except for the Starter and Wrapper roles which should

Table 6 Descriptive statistics (*N*=252)

Variables	% of data at each value						Mean	SD	Min	Max
	0	1	2	3	4	5				
Outcome variables										
Pivotal Post	94	6								
Knowledge Construction (KC)		60	3	16	4	17				
Explanatory variables										
After 1st pivotal post	51	49								
Two posts per week	25	75								
Graduate student / Teacher group	50	50								
Graduate student	63	37								
Teacher	85	15								
Starter	94	6								
Inventor	90	10								
Importer	90	10								
Mini-me	91	9								
Elaborator	90	10								
Questioner	91	9								
Devil's Advocate	90	10								
Traffic Director	90	10								
Synthesizer	90	10								
Wrapper	94	6								
Post Number in Thread							9.0	5.5	1	22
New Idea	77	23								
Bring in Source	88	3	9							
Use Theory	15	16	69							
Respond	55	7	38							
Give Direction	70	12	18							
Summarize	72	9	19							

and did make only one corresponding functional post per discussion. Over half the posts were in KC Phase 1 (Sharing Information), with substantial numbers in KC Phase 3 (Negotiating Meaning) and KC Phase 5 (Agreeing and Applying). Few focused on discrepancies or contradictions (KC Phase 2 [Exploring Dissonance] or KC Phase 4 [Testing and Modifying]).

Identifying pivotal posts

A total of 16 pivotal posts were indentified in the 16 discussions. Most discussions (12 of 16) had a single pivotal post (two time segments); two discussions had two pivotal posts (three segments) and two had none (one segment). In addition, most segments had a majority of posts in a single KC phase, though some mixed phase segments were observed; see Fig. 2 for examples. The Synthesizer and Wrapper roles contributed the majority of the pivotal posts (10 of 16), and these pivotal posts often were in KC phases 3 or 5 (7 pivotal posts each), with Extensive Summaries (13 pivotal posts). Other pivotal posts had varied characteristics.

Modeling pivotal posts

Assigned role and current post characteristics accounted for a substantial portion of the pivotal post variance (28%, see Fig. 3). Compared to other roles, Synthesizers' and Wrappers' posts were more likely to be Extensive Summaries, and Extensive Summaries were more likely than other functions to be pivotal posts. Other variables (including

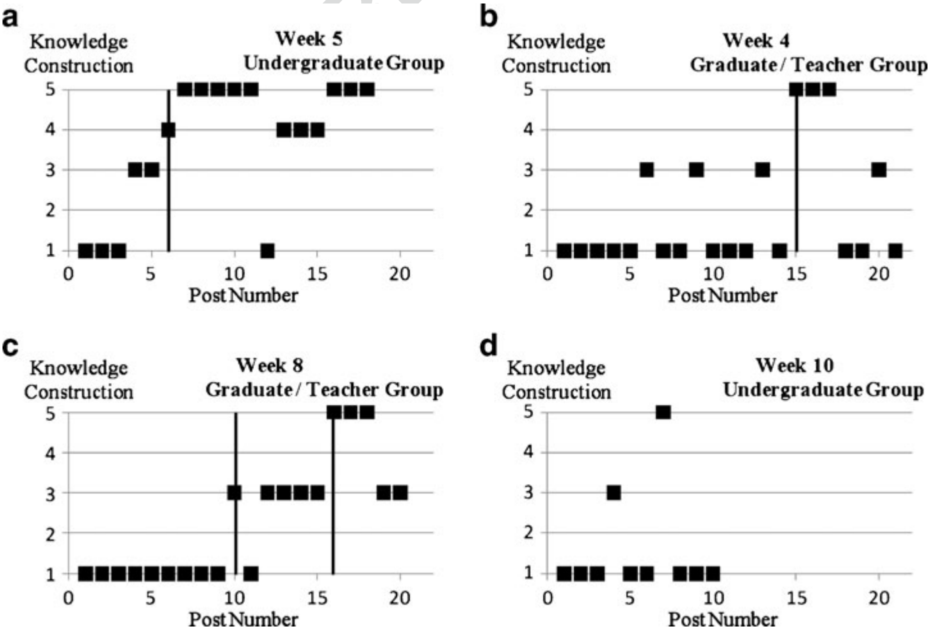

Fig. 2 Examples of discussions with (**a**) one pivotal post (two time segments); all segments with majority of posts in single KC phase; (**b**) one pivotal post (two time segments); last segment with no majority KC phase; (**c**) two pivotal posts (three time segments); (d) no pivotal posts (one time segment)

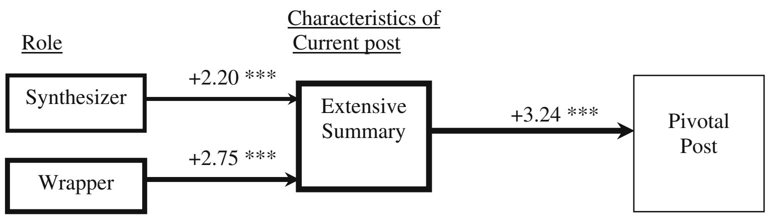

Fig. 3 Path diagram of final model predicting pivotal posts. Numbers shown are regression coefficients. Solid lines indicate positive effects. Thicker lines indicate larger effect sizes. *p<.05, **p<.01, ***p<.001

discussion group and post order in the discussion) were not significant. Notably, Minor Summaries were not significantly more likely to be pivotal posts.

Modeling KC

Discussion segment, role, characteristics of the current post, and characteristics of the two prior posts accounted for much of the variance in the KC phase of a post (see Fig. 4). Only 23% of the differences in KC phases occurred across discussions; 77% of the differences were within each discussion. Across all discussions, Synthesizers and Wrappers posted many more Summaries compared to other roles. Posts with Summaries (Minor or Extensive) exhibited a higher KC phase on average. Thus, Synthesizer and Wrapper posts averaged higher KC phases compared to other roles with the effect fully mediated by the Summary function.

The results also show three time-specific relationships. First, KC was substantially higher in posts after a pivotal post than before one (as indicated by the Kruskal-Wallis median equality test, Sheskin 1997). Second, Summaries were more likely to occur after a pivotal post. Third, there were two links between explanatory variables and KC that existed only after a pivotal post has occurred (in second and third discussion segments): one, if the

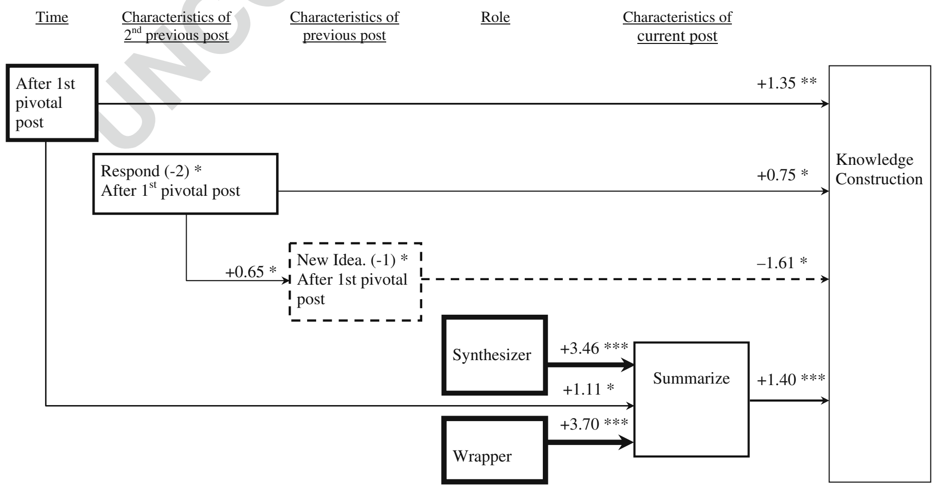

Fig. 4 Path diagram of final model predicting KC. Numbers shown are regression coefficients. Solid lines indicate positive effects. Dashed lines indicate negative effects. Thicker lines indicate larger effect sizes. *p<.05, **p<.01, ***p<.001

previous post had a New Idea, the current post averaged lower KC; and two, if a post was Responsive, the following post was more likely to be a New Idea and KC was slightly lower two posts later (indirect and direct effects combined).

All other variables were not significant. Notably, the order of a post in the discussion did not affect KC, showing that later posts did not necessarily show higher KC. Furthermore, neither discussion group nor week explained a significant amount of variance in the KC phase of post.

Discussion

This study used a temporal approach to analyze patterns of collaborative KC in a semester-long series of role-based online discussions by 21 students. The study revealed a distinct KC pattern that emphasized sharing (Phase 1), negotiating (Phase 3) and summarizing (Phase 5) ideas, but not exploring dissonance (Phase 2) or testing and revising tentative syntheses (Phase 4). A single pivotal post divided most of the discussions into two distinct segments. Segments were generally characterized by a majority of posts in a single KC phase with later segments showing higher KC than earlier segments. The pivotal posts that initiated later segments were typically contributed by students assigned the Synthesizer or Wrapper roles and contained Extensive Summaries that elevated KC both immediately and in subsequent posts. Several additional time-specific relationships between KC and characteristics of previous posts were observed. Below we discuss these results with respect to our research questions and the previous literature as an illustration of the power of our temporal analysis to investigate collaborative KC processes.

Research question 1: What pattern(s) characterize the KC process during an online asynchronous discussion with assigned roles?

Like previous studies of online discussions with assigned roles, our analysis allowed us to examine the proportions of posts in each KC phase. As in prior work (Gunawardena et al. 1997; Schellens et al. 2005), most posts in this study were in KC Phase 1 (Sharing Information) showing that students produced new ideas much more often than they considered existing ideas. In addition, similar to some prior findings (De Wever et al. 2008; Schellens et al. 2007), this study also showed a greater proportion of posts in KC Phase 3 (Negotiating Meaning) than in Phase 2 (Exploring Dissonance). This is different from a pattern in which the proportion of posts decreases for each successive KC phase (De Wever et al. 2007, 2010). In comparison with past studies, the learners in this study had many more posts in KC Phase 5 (Agreeing and Applying), though still few posts in KC Phase 4 (Testing and Modifying). The preponderance of posts in the initial (1) and convergent (3 and 5) phases and lack of posts in judgmental KC phases (2 and 4) suggest that these groups were focused on reaching consensus.

Moving beyond aggregate counts of posts, our analysis probed the process of knowledge construction by identifying segments of KC patterns. This let us empirically test the underlying premise that groups construct knowledge through a specific sequence of phases and Gunawardena et al.'s (1997) theoretically proposed patterns of KC (see Table 2). Most of the online discussions studied had at least two distinct segments of discussion, which rejects the KC pattern 4 hypothesis (no distinct segments of KC). Segments were generally characterized by a majority of posts in a single KC phase, with later segments showing higher KC; this rejects the KC patterns 1b and 2b hypotheses (which include regressive segments). In particular, the discussions often had an initial segment with mostly KC Phase 1 posts (Sharing Information) followed by a statistically identified pivotal post which elevated the discussion to a segment with a majority of posts in KC phases 3 or 5. This rejects KC pattern 1a (which requires a segment for each KC phase) and provides strong support for the KC pattern 2a hypothesis (strictly progressive segments with some KC phases skipped). However, nearly a quarter of the later segments did not have a majority KC phase which also provides some support for the KC Pattern 3 hypothesis (mixed KC phase segments).

These results differ from the two theoretically "complete" patterns suggested by Gunawardena et al. (1997; KC Patterns 1a and 1b), both which include segments for all five phases of KC. Notably, in the original conceptualization, exploration of dissonance and testing a proposed synthesis are important to KC, but these results show that in some cases groups can engage in KC Phase 5 processes without KC Phases 2 or 4 in this context. Importantly, while some disagreeing posts in KC Phases 2 and 4 were made, these contributions did not propel the group into a critique-focused segment of discussion. The lack of disagreements in the discussions may be due to concerns about social relationships (Chiu 2008b), inadequate concern for the quality of the solution, or a notion of agreement as an indicator of a quality solution.

Whether the absence of disagreements affects the quality of knowledge construction outcomes is an important question both empirically and theoretically and at both the group and individual levels. At the group level, exploration of dissonance between ideas is thought to be important to lay the foundation for meaningful negotiation and co-construction of knowledge (Gunawardena et al. 1997). Thus, we might suspect that discussions with few disagreements have not truly considered multiple ways to address the discussion task nor evaluated reasons for choosing one over another and thus would produce a low quality of constructed knowledge. In contrast, it is also possible that in some discussions which lack explicit disagreement, students are engaging in these processes tacitly (Gunawardena et al. 1997). A finding that discussions without disagreements still yield a high quality of constructed knowledge, could indicate such tacit processes are occurring or a need to question the function and necessity of the two judgmental phases for effective KC.

At the individual level, the cognitive dissonance caused by engaging with a disagreeing idea is considered important as a trigger for learners to reconsider their existing ideas and construct new understandings (Piaget 1985; also see "conflict scripts" in Dillenbourg and Jermann 2007). If disagreements are not present as part of the KC process in a discussion, then even if the group comes to an acceptable conclusion, individual learners may not have made significant changes in their personal understandings. Such a finding would indicate a need for further scripting of discussions or a change to the task structure to support students in critically probing each other's ideas. In future work, we will explore these issues by empirically studying how the quality of the discussion process influences independent learning outcome measures at both the group and individual level.

Another issue for future inquiry is the meaning of the mixed KC phase segments. Mixed KC phase segments may provide evidence that sometimes students operate in different KC phases and thus don't engage in a shared mode of interaction. Another possibility is that subgroups may engage in parallel conversations that are internally coherent, but in different KC phases from each other. Further investigation can examine this issue in greater detail and draw connections between these KC processes and learning outcomes.

Research question 2: Does a summary midway through the discussion affect subsequent KC?

Like past studies, our results show that roles encouraging summarization (Synthesizer, Wrapper) yielded posts in significantly higher KC phases than posts by roles which did not (De Wever et al. 2007; Schellens et al. 2005, 2007). More importantly, our temporal analysis allowed us to examine the effects of these summarizing posts on the group's patterns of collaborative KC. As hypothesized, mid-discussion extensive summaries created by students in the Synthesizer role were often pivotal posts that initiated new discussion segments with posts in elevated phases of KC. Due to a large number of late student posts, many Wrapper summaries inadvertently ended up mid-discussion and also acted as pivotal posts that advanced the KC phase of the discussion. Notably, only one post with a minor summary was a pivotal post, suggesting that minor summaries are qualitatively different from extensive summaries.

These results suggest that reading the extensive summaries facilitated contributions at higher KC phases on average, thus advancing the group's KC process. Particularly, the integrative value of extensive summaries (Hara et al. 2000; Tagg 1994) can help students consolidate their understanding of the different ideas contributed and draw on the previous discussion to negotiate shared understandings (Phase 3) or apply their newly-constructed knowledge (Phase 5). In this way, the extensive summary can coordinate group activity and ground subsequent discussion. This result illustrates the power of our analysis to illuminate how individual's posts in a discussion can influence group processes of knowledge construction.

Research question 3: How do the assigned roles and functions of recent posts affect the current KC process?

Two characteristics of recent posts had small effects on the KC of the current post. First, after a pivotal post (often an extensive summary) had occurred, posts with New Ideas were more likely to be followed by lower KC posts (such as other new ideas). Second, after a pivotal post had occurred, a Responsive post was more likely to be followed by a post with a New Idea and then with a subsequent post in a lower KC phase (see Fig. 4).

If substantiated in future work, these findings raise additional questions about the relationship between the KC process and the quality of its resulting knowledge. While new ideas after extensive summaries might hinder immediate efforts to advance the KC *process* (since they draw away from synthesis), returning to a lower KC phase might ultimately help the group produce a higher quality constructed knowledge *product*. For example, a new idea contributed after the group has come to a final agreement (KC Phase 5) could lead someone to suggest an additional revision that improves the idea (KC Phase 4). Thus, the connections between these KC micro-processes and the quality of their resultant knowledge products require investigation.

These results also show how this method can identify both time-dependent effects and sequences of effects. The connections between New Ideas, Responsiveness and KC occur in particular time periods (only after the first pivotal post) and demonstrate linkages across a sequence of three posts: a responsive post is linked to new ideas in the next post, which in turn is linked to the KC in the third post.

Implications

Our findings have three implications for researchers, teachers and online learning designers. Most importantly, this study demonstrated a method for studying interdependencies in the

KC process and provided empirical evidence about how learners' contributions to online discussions influence one another. Using a combination of content analysis and statistical discourse analysis, our approach identified the number and locations of pivotal posts in the KC process, tested explanatory models of these pivotal posts and tested explanatory models of KC processes at multiple levels–allowing for different effects across time segments, across discussions, across groups and across weeks. This method allowed us to detect extensive summaries' ignition of new discussion segments with elevated KC and how sequences of actions (of new ideas, and responsiveness) across multiple posts can influence KC in the current post. This contrasts the view of online discussions as fractured and incoherent with little interactivity (Herring 1999; Reyes and Tchounikine 2003; Thomas 2002). Moreover, the combination of significant micro-level effects (among sequential posts), meso-level effects (across discussion segments) and non-significant macro-level effects (across groups and discussion topics) highlight the importance and the need for fine-grained temporal analyses to address research questions about the relationships among posts in online discussions.

Second, to our knowledge, this is the first study to analyze Gunawardena et al.'s (1997) KC phases using a statistical method that aligns with its ontology as a process. This allows us to extend prior work examining aggregate proportions of posts in each KC phase and pose important questions about the nature of KC as a process. The result that a pivotal post ignited a new distinct segment of conversation at a higher KC phase (often phase 3 or 5) in many discussions supports the meso-level structure of progressive, well-defined KC phases (Gunawardena et al. 1997). At the same time, the many posts in KC phases 3 and 5 without prior KC phase 2 or 4 segments respectively questions the necessity of the judgmental KC phases as pre-requisites to the synthetic phases. Future research is needed to examine whether the presence or absence of KC Phases 2 and 4 in the discussion process impacts the resulting constructed knowledge product and learning outcomes at the group and individual levels. If future studies find these KC phases to be be important, online designers and instructors educators might explicitly articulate conversational functions to align with them. For example a "critique" function could be proposed to align with KC phase 2 and a "probe and test solutions" function could be crafted to align with KC phase 4. These functions could then be encouraged using assigned roles and other scripting techniques.

Finally, this study expanded the importance of discussion summaries, specifically extensive summaries. Extensive summaries in the middle of the discussion not only increased KC immediately but were also often pivotal posts that radically increased KC in the following discussion segment. The high proportion of Synthesizers' posts that were extensive summaries further suggests that learners are capable of enacting this role satisfactorily. Thus, online designers and instructors can consider assigning a Synthesizer role as a simple intervention to increase midway extensive summaries and advance the knowledge construction process in online discussions. Role instructions provided to learners can support their creation of extensive summaries (rather than minor ones) by explicitly encouraging learners to weave together multiple posts to draw out key ideas and themes that have arisen in the discussion. In a similar vein, educators can consider how subsequent discussions can build off the Wrapper's summary post, either in future online discussions, or as part of an in-class follow-up (in the case of blended instruction). Future work can expand on this finding by theorizing and testing different mechanisms by which extensive summaries may influence the discussion as pivotal posts; for example by helping individuals to consolidate their understanding, supporting the group in maintaining joint attention, and providing a grounding for subsequent discussion.

Limitations and future research

Limitations of these findings include coding granularity, the study's sample size, and the generalizability of findings to other kinds of course content, structures and settings. This study used one particular model to conceptualize and asses the KC process, but there are also many other frameworks being used in the CSCL community to investigate knowledge construction (e.g. Pena-Shaff and Nicholls 2004; Weinberger and Fischer 2006). As Gunawardena et al.'s (1997) model explicitly conceptualizes the sequential relationship between KC phases, it was particularly suited to temporal analysis, but it also has limitations. For example, this KC coding scheme does not differentiate quality: a creative, detailed proposed task solution may contribute more to a discussion than a simple opinion but both are coded as KC Phase 1 posts (cf. Veerman and Veldhuis-Diermanse 2001). Due to the small number of participants, these data are also not necessarily representative of interactions among students in different groups or classes. Finally a model of KC phases during discussions may differ for other subject matter (e.g., mathematics), other task structures (e.g., open class discussions without roles), or other settings (voluntary non-academic contexts).

Despite these limitations, the study demonstrates the statistical power of our method to analyze interactions at the post level while simultaneously allowing for systematic analyses of large numbers of online discussions. Future studies will test the generalizability of these findings and can examine more participants studying different content across varying task structures using a variety of models to conceptualize and assess the KC process. In addition, we will extend this work by empirically testing the relationship between different discussion processes and independent knowledge product and learning outcome measures.

Conclusion

This paper has shown a new approach for analyzing temporal patterns of knowledge construction using a combination of content analysis and statistical discourse analysis. We coded data from online discussions in a college course in which 21 students were assigned weekly roles with Gunawardena et al.'s (1997) scheme of five phases of KC. We then statistically identified pivotal posts that initiated new segments of KC during the discussions, tested hypotheses about patterns of KC phases and modeled the effects of role assignments on these patterns. Specifically, results indicated that most online discussions had one pivotal post that distinguished two distinct discussion segments, the first dominated by a lower KC phase and the second dominated by a higher KC phase. These results support the progressive nature of Gunawardena et al.'s KC scheme, but not the necessity of the earlier phases to reach KC phase 5. Furthermore, the pivotal posts identified were often extensive summaries written in the middle of the discussion by students assigned a Synthesizer or Wrapper role. This result suggests that assigning a summarization role in the middle of the discussion rather than near the end can aid group progress to more advanced phases of KC. Our model of KC also showed that sequences of recent posts were linked to KC in the current post and identified how these effects differed across time. This case study is just one example of how our approach can be used to analyze temporal patterns of KC to address fine-grained research questions about collaborative processes in online discussions.

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